Executive Summary

The existence of serious water pollution problems in the United States, first recognized during the 1920s and 1930s and increasingly well documented during the 1940s through 1960s, led to the recognition that the practice of discharging raw sewage and the use of only primary treatment in publicly-owned treatment works (POTWs) were generally inadequate technologies for wastewater disposal.

Excessive loading of organic matter, nutrients, sediment, pathogens, and other pollutants into surface waters, combined with natural hydrologic (low-flow) conditions, frequently accounted for incidences of dissolved oxygen (DO) depletion, fish kills, nuisance algal blooms, and bacterial contamination in rivers, lakes, and estuaries. Many of the United States' most famous water bodies, including Lake Erie, New York Harbor, and the Hudson, Upper Mississippi, Potomac, Chattahoochee, Delaware, and Ohio Rivers fell victim to these symptoms.

For the first half of the 20th century, pollution in the Nation's urban waterways resulted in frequent occurrences of low dissolved oxygen, fish kills, algal blooms, and bacterial contamination.

In 1948, the 80th Congress encapsulated its frustration with the situation when it declared that

> *"... The pollution of our water resources by domestic and industrial wastes has become an increasingly serious problem for the rapid growth of our cities and industries. ... Polluted waters menace the public health through the contamination of water and food supplies, destroy fish and game life, and rob us of other benefits of our natural resources."*
>
> **- Senate Report No. 462, 1948**

An Increased Federal Policy Role in the Control of Water Pollution

National policy for water pollution control has been primarily legislated in the Federal Water Pollution Control Act. First passed in 1948, the original act has been amended numerous times (in 1956, 1961, 1965, 1966, 1970, 1972, 1977, 1981 and 1987) to gradually expand the authority of the federal government in regulating pollutant discharges from point sources to surface waters. Until enactment of the 1972 (PL 92-500) and more recent amendments, now known as the Clean Water Act (CWA), the primary authority and responsibility for water pollution control was at the state level.

The 1972 CWA shifted primary authority for water pollution control from the states to the federal government.

Unfortunately, there was a great diversity among the states in terms of ability and willingness to pay the costs of building and upgrading POTWs and to enforce pollution control laws. Lack of local water quality standards, monitoring data, and penalties for violators exacerbated the situation. Despite 49 joint state-federal enforcement conferences that were convened after the 1965 Amendments to abate critical water pollution problems, national progress in improving water quality was hindered in part, because, unless a state formally requested intervention by the federal government, federal authority for regulating discharges was restricted to interstate and coastal waters.

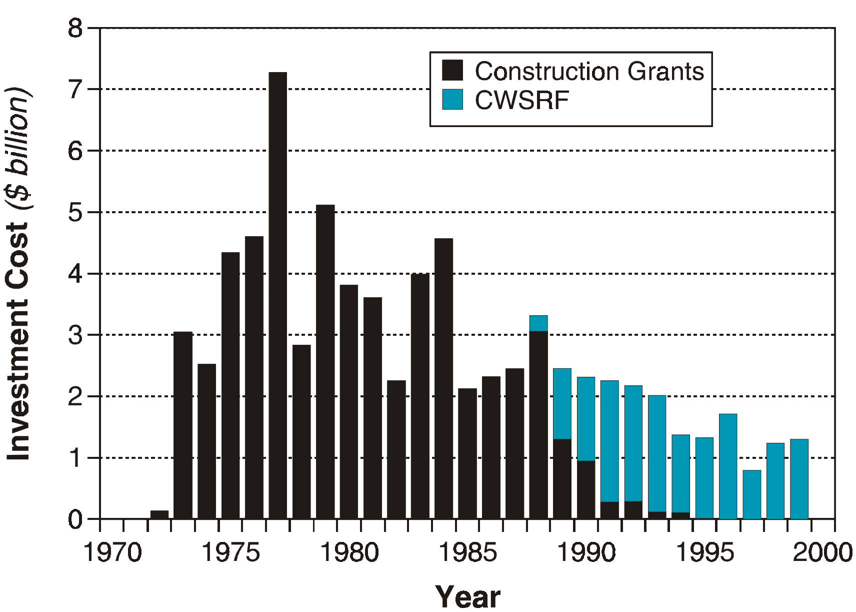
Public awareness of nationwide water pollution problems served as a political catalyst to shift increased authority and responsibility for the regulation of water pollution control from the

From 1970 to 1995, USEPA distributed $61.1 billion in grants for POTW upgrades to secondary treatment or greater and, since 1988, over $16.1 billion in support for state revolving loan funds for a wide range of water quality improvement projects.

states to the federal government. *Establishment of a national policy requiring secondary treatment of municipal wastewater as the minimum acceptable technology supplemented by more stringent water quality-based effluent controls on a site-specific, as-needed basis was a key provision of the 1972 act.* This mandate, coupled with an increase in funding assistance to municipalities through the Construction Grants Program, led to a dramatic increase in the number of POTWs with secondary and advanced treatment capabilities. Congress assumed that these actions would directly support the long-term goal of the CWA, the national attainment of "fishable and swimmable" waters.

Figure 1

Annual funding provided by USEPA's Construction Grants and CWSRF Programs to local municipalities for improvements in water pollution control infrastructure from 1970 to 1999. Costs reported in current year dollars. *(Data from USEPA GICS database and CWSRF Program.)*



The National Investment in Municipal Wastewater Treatment

A total of $61.1 billion ($96.5 billion as constant 1995 dollars) was distributed to municipalities through USEPA's Construction Grants Program in the 25-year period from 1970 to 1995 in support of the CWA's municipal wastewater treatment program (Figure 1). An additional $16.1 billion (capitalization) was also distributed to the states through the Clean Water State Revolving Fund (CWSRF) Program from 1988 through 1999. Including the state contributions and loan repayments, the CWSRF loan program assets have grown to over $30 billion since 1988 and are funding about $3 billion in water quality projects each year.

In terms of promoting the minimum acceptable technology-based standard of secondary treatment nationwide, this investment was an outstanding success. By 1996, the number of POTWs offering less than secondary treatment dwindled to less than 200 (down from 2,435 in 1968 and 4,278 in 1978). Correspondingly, there was a dramatic increase in the number of facilities offering secondary treatment or greater (from 10,052 facilities in 1968 to 13,816 facilities in 1996).

In 1968, 72 percent of the Nation's POTWs were providing secondary treatment and less than 1 percent were providing greater than secondary treatment (out of 14,051 facilities). By 1996, 59 percent of the Nation's POTWs were providing secondary treatment and 27 percent were providing greater than secondary treatment (out of 16,024 facilities).

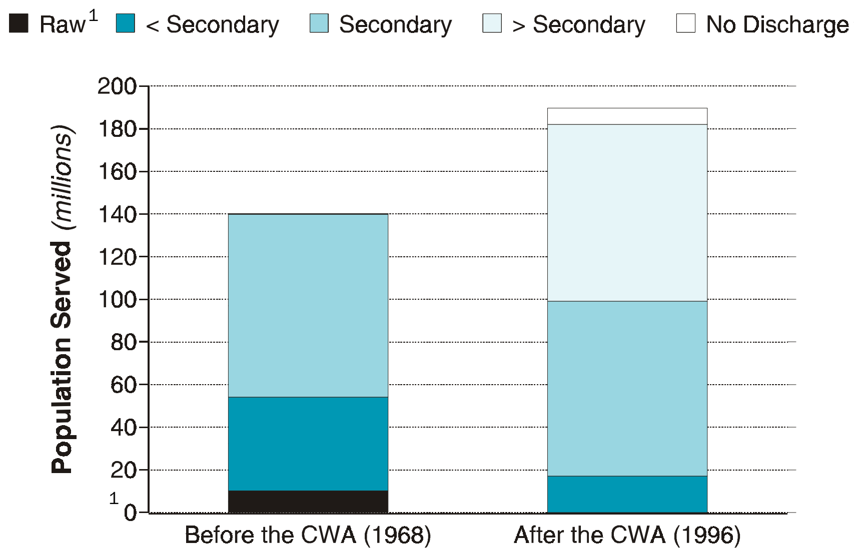
The number of people served by POTWs with secondary or greater levels of wastewater treatment almost doubled between 1968 and 1996!

The success of these national investments is also seen by the increase in the number of people served by POTWs, which shifted dramatically between 1968 (before-CWA) and 1996 (after-CWA), as shown in Figure 2. The story told in Figure 2 is summarized below.

- *The overall number of people served by POTWs increased from 140.1 million in 1968 to 189.7 million in 1996 (a 35 percent increase).*
- *The number of people relying on POTWs with less than secondary treatment dropped rapidly after passage of the 1972 CWA.* In 1968, about 39 percent (54.2 million) of the 140.1 million people served by POTWs received less than secondary treatment (raw and primary). By 1996, this percentage was reduced to about 9 percent (17.2 million) of the 189.7 million people served by POTWs. This 9 percent includes approximately 5.1 million people currently served by POTWs with CWA Section 301(h) waivers allowing less than secondary treated effluent discharged to deep, well-mixed ocean waters.
- While the number of people served by POTWs with secondary treatment remained fairly constant between 1968 and 1996 (a slight decrease of 3.7 million people or about 4 percent of the population), the number of people provided with greater than secondary treatment increased significantly (from 0.3 million people in 1968 to 82.9 million people in 1996). *Stated another way, the U.S. population served by POTWs with secondary or greater treatment almost doubled between 1968 and 1996 from 85.9 million people in 1968 to 164.8 million people in 1996!*

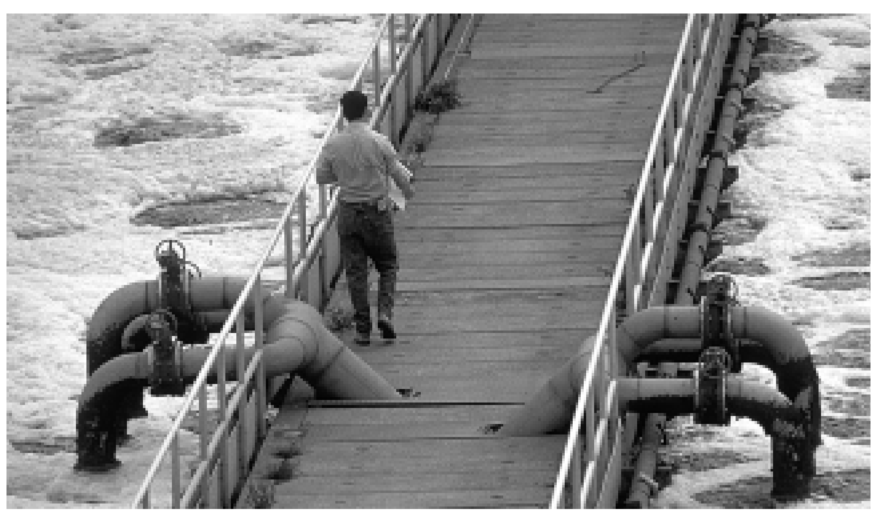
Figure 2

Population served by POTWs in 1968 (before the CWA) and in 1996 (after the CWA) by treatment type. *(Data from U.S. Public Health Service municipal wastewater inventories; USEPA Clean Water Needs Surveys; USDOI, 1970; USEPA, 1997.)*



[1] Raw discharges were eliminated by 1996.

[2] Data for the “no-discharge” category were unavailable for 1968.



Until now, no national-scale evaluation of the effectiveness of the CWA's technology- and water quality-based control policies has been accomplished.

Was the Public's Investment in POTWs Worth It?

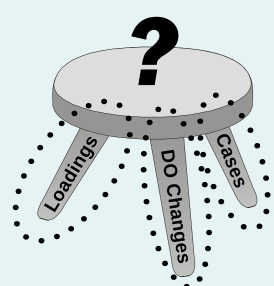
Questions concerning the environmental benefits, as well as the cost-effectiveness of the national investment in municipal wastewater treatment have been raised by Congress and by special interest, environmental, and business advocacy groups. In the 25 years after the enactment of the CWA, studies have attempted to evaluate progress in achieving the goals of the CWA by documenting (a) administrative actions (e.g., numbers of discharge permits and enforcement actions) and programmatic evaluations (see Adler et al., 1993); (b) trends in national wastewater infrastructure (e.g., population served by secondary or greater treatment levels, effluent loading rates); (c) state and national inventories of waterways meeting designated uses (e.g., 305(b) reports); and (d) changes in water quality following wastewater treatment plant upgrades for specific waterways.

Evaluations of water quality conditions in the United States include a pre-CWA national water quality analysis of conditions from the 1940s through the 1960s (Wolman, 1971; USEPA, 1974) and post-CWA assessments of the national effectiveness of the 1972 CWA (e.g., Smith et al., 1987a, 1987b). Assessments of local (Isaac, 1991; GAO, 1986), regional (Patrick et al., 1992), and national water quality conditions (Smith et al., 1992) have demonstrated improvements in some water quality constituents following upgrades to secondary or greater levels of wastewater treatment at municipal facilities.

There is, however, no study that has attempted a national-scale comprehensive evaluation of the effectiveness of the CWA's technology- and water quality-based effluent control policies in achieving the "fishable and swimmable" goals of the act (Mearns, 1995).

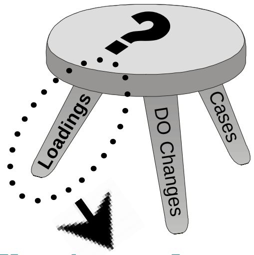
STUDY OVERVIEW: The "Three-Legged Stool" Approach

This study takes a unique, three-pronged approach for answering the prima facie question—*Has the Clean Water Act's regulation of wastewater treatment processes at POTWs been a success?* Or posed more directly, *How has the Nation's water quality conditions changed since implementation of the 1972 CWA's mandate for secondary treatment as the minimum acceptable technology for POTWs?*



This study takes a unique three-pronged approach to evaluate nationwide progress in water quality conditions since the enactment of the 1972 CWA.

The three-pronged approach described below (and presented in the companion document, USEPA, 2000) was developed so that each study phase could provide cumulative support regarding the success, or failure, of the CWA-mandated POTW upgrades to secondary and greater than secondary treatment. Using the analogy of a three-legged stool, the study authors felt that each leg must contribute support to the premise of CWA success. If one or more legs fail in this objective, the stool will be unable to "stand up."



The First Leg: An examination of BOD loadings before and after the CWA

The amount of BOD_5 and BOD_U discharged from POTWs to the Nation's waterways declined by about 45 percent and 23 percent, respectively, after the 1972 CWA, despite a 35 percent increase in influent loadings!

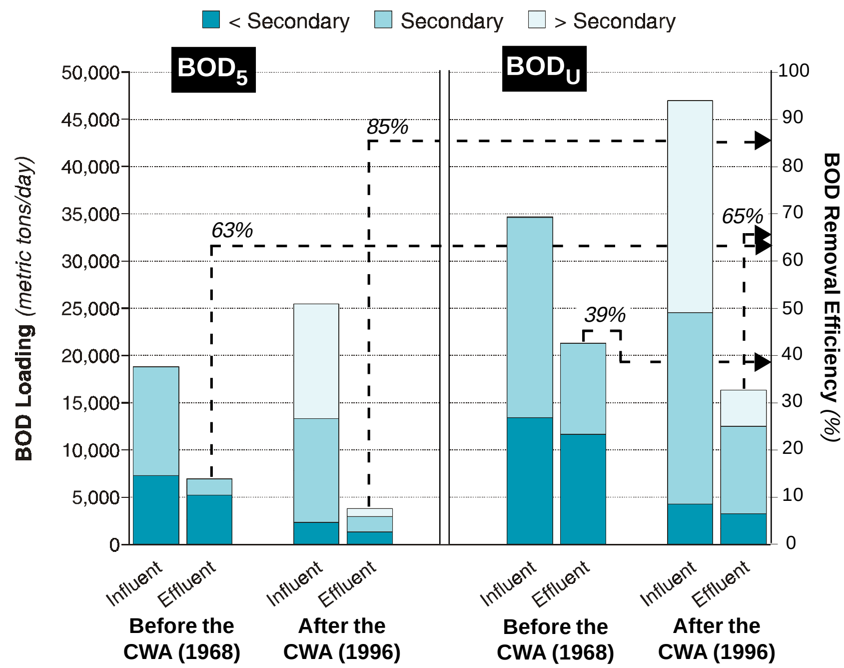
As increasing numbers of people hooked into more and upgraded POTWs, there was a corresponding rise in influent BOD[1] loading nationwide to these facilities. Figure 3 presents the amount of influent BOD loading to "less than secondary," secondary, and "greater than secondary" facilities for 1968 and 1996 (years representing before and after the CWA). BOD loadings are shown both as BOD_5 (carbonaceous BOD i.e., oxygen demand from the decomposition of organic carbon) as well as BOD_U (ultimate BOD, which includes nitrogenous BOD i.e., oxygen demand from the decomposition of ammonia and organic nitrogen, in addition to carbonaceous BOD).

As shown, total influent loading of BOD_5 increased by about 35 percent, from 18,814 to 25,476 metric tons per day. Similarly, total influent loading of BOD_U increased by about 35 percent, from 34,693 to 46,979 metric tons per day. Fortunately, this situation was counteracted by the CWA wastewater treatment mandates which resulted in rising BOD removal efficiencies (Figure 3).

In 1968, the national aggregate removal efficiencies stood at about 63 percent and 39 percent for BOD_5 and BOD_U, respectively. By 1996, national aggregate removal efficiencies rose to nearly 85 percent and 65 percent, respectively!

Figure 3

Influent and effluent loading of BOD to and from POTWs in 1968 (before the CWA) and in 1996 (after the CWA) by treatment type and associated BOD aggregate removal efficiencies. *(Data from U.S. Public Health Service municipal wastewater inventories; USEPA Clean Water Needs Surveys; USDOI, 1970; USEPA, 1997.)*



Consequently, the net result was decreasing levels of effluent BOD loading to the Nation's waterways (Figure 3). In 1968, the total effluent loadings for BOD_5 and BOD_U stood at about 6,932 and 21,281 metric tons per day, respectively. By 1996, these amounts dropped to 3,812 metric tons per day for BOD_5 (a 45 percent decline) and 16,325 metric tons per day for BOD_U (a 23 percent decline), despite a corresponding 35 percent increase in influent BOD loadings! Since many POTWs operate at even higher BOD removal efficiencies, these design-based effluent load reductions are understated, compared to actual data reported in the Permit Compliance System (PCS), which may vary somewhat from year to year.

[1] BOD, or " Biochemical Oxygen Demand" is a measure of the oxygen-consuming organic matter and ammonia-nitrogen in wastewater. The higher the BOD loading, the greater the depletion of oxygen in the waterway.

Without continued improvements in wastewater treatment infrastructure, future population growth will erode away many of the CWA achievements in effluent loading reduction.

Based on middle level population projections, effluent loading rates of BOD_U in 2016 would be similar to loading rates experienced in the mid-1970s, only a few years after the CWA!

Figure 4

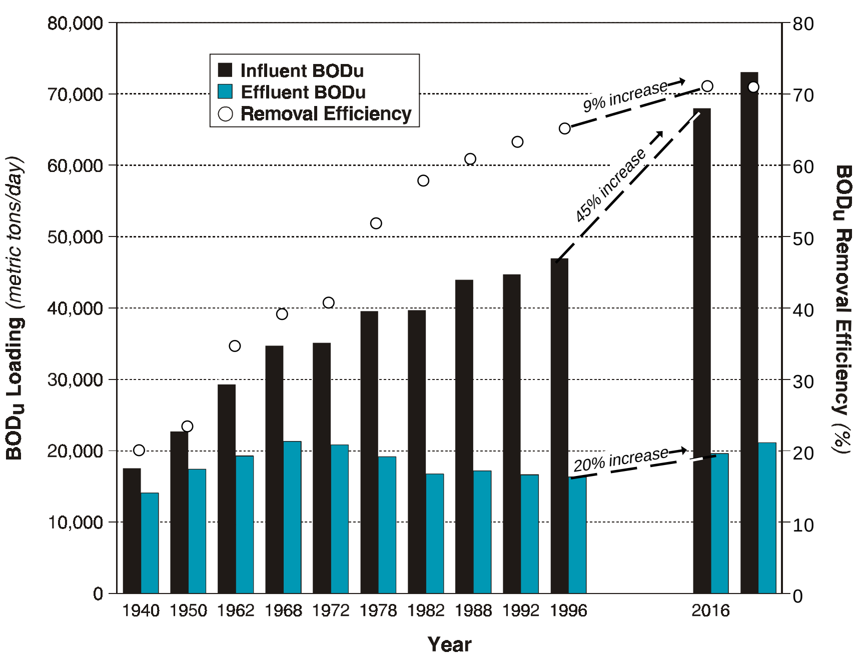
Projections of design-based, national effluent BOD_U loadings through 2025 using middle-level U.S. population projections. *(Population projection data from U.S. Census, 1996.)*

Assumptions:

Influent flow is a constant 165 gallon/capita-day[1] with a BOD_U of 396.5 mg/L

Projection Results

	1968	1972	1978	1996	2016	2025
Population served *(millions)*	140.1	141.7	155.2	189.7	275.0	295.0
Percent of total population	71%	69%	70%	72%	88%	88%
Design removal efficiency *(BOD_U)*	39%	41%	52%	65%	71%	71%
Effluent BOD_U *(metric tons/day)*	21,280	20,831	19,147	16,325	19,606	21,090



[1] 165 gal/capita-day is based on the mean of population served and wastewater flow data in the Clean Water Needs Surveys for 1978 through 1986 and accounts for residential, commercial, industrial, stormwater, and infiltration and inflow components.

The dynamic relationship between influent BOD loading, BOD design removal efficiency, and effluent BOD loading creates an important model for planning new investments in wastewater treatment infrastructure (Figure 4). Based on the data reported in the 1996 Clean Water Needs Survey Report to Congress (USEPA, 1997), the overall design BOD removal efficiency is likely to increase somewhat as there is an apparent trend toward a higher proportion of advanced (greater than secondary) POTWs. In the next twenty years, however, the proportion of the U.S. population served by POTWs is also likely to increase as the urban population of the nation increases.

Using the assumptions listed in Figure 4, and using middle-level population growth projections from the Census Bureau (U.S. Census, 1996), it was estimated that by 2016 nearly 275 million people will be served by POTWs that discharge to surface waters. Assuming a 165 gal/capita-day influent flow and 396.5 mg/L concentration of influent BOD_U, this growth (1996-2016) would result in a 45 percent increase in influent BOD_U loading to POTWs (68,030 metric tons per day) and a 20 percent increase in effluent BOD_U loading to surface waters (19,606 metric tons per day). *These projected effluent BOD_U loadings in 2016 are similar to levels that existed in the mid-1970s, only a few years after the CWA!* Projecting further into the future, effluent BOD_U loadings in 2025 (21,090 metric tons per day) would be similar to loading rates experienced in 1968 (21,280 metric tons per day), when they had reached a historic maximum level!

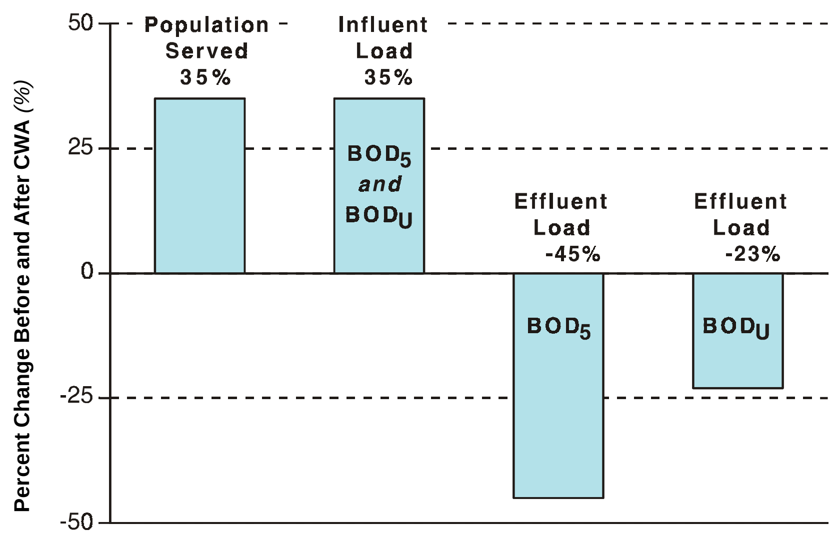
Future water quality management strategies will need to consider integrated point and nonpoint source controls since POTWs account for only 21 percent of the total BOD_5 loadings nationwide.

These types of projections underscore the importance of the need to continually invest in improvements to wastewater treatment infrastructure in order to maintain and improve pollutant removal efficiencies. *Without these improvements, many of today's achievements in water pollution control will be overwhelmed by tomorrow's demand from urban population growth.* A recent report by the Water Infrastructure Network (WIN, 2000) also documents the risk of reversing environmental gains over the last three decades.

While POTWs are often the dominant source of BOD effluent loading in major urban areas, other sources affect waterways on a national scale. In order to put POTW effluent loading in perspective, USEPA's National Water Pollution Control Assessment Model (NWPCAM) and input data from USEPA's Permit Compliance System (PCS) and the Clean Water Needs Survey (CWNS) were used to examine current BOD_5 loading (ca. 1995) for several key point and nonpoint sources (Bondelid et al., 1999).

Figure 5

Percent changes in population served, influent BOD loading, and effluent BOD_5 and BOD_U loading before and after the 1972 CWA (1968 to 1996). *(Data from U.S. Public Health Service municipal wastewater inventories; USEPA Clean Water Needs Surveys; USDOI, 1970; USEPA, 1997.)*

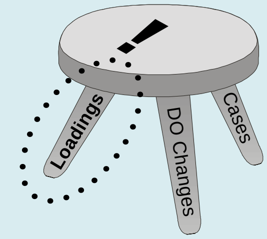


From a national perspective, it was found that currently (ca. 1995) POTW BOD_5 loadings account for only about 38 percent of total point source loadings and only 21 percent of total loadings (point and nonpoint). Industrial facilities (major and minor) currently account for about 62 percent of total point source BOD_5 loadings and 34 percent of total BOD_5 loadings. Clearly, continued improvement in water quality conditions of the Nation's waterways will require an integrated strategy to address all pollutant sources, including both point and nonpoint sources.

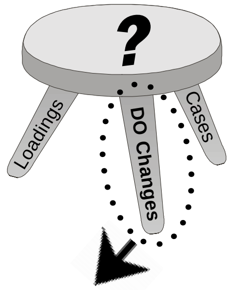
The first leg of the three-legged stool approach focused on the Nation's investment in building and upgrading POTWs to achieve at least secondary treatment. Based on this historical BOD loading analysis, it is clear that the CWA's mandate for secondary treatment as the minimum acceptable treatment technology, supplemented by more stringent water quality-based effluent controls on a site-specific basis, combined with financial assistance from the Construction Grants and CWSRF Programs, resulted in a dramatic nationwide decrease in effluent loading of BOD from POTWs into the Nation's waterways (see Figure 5).

The 45 percent nationwide reduction in effluent BOD_5 loading and the 23 percent reduction in effluent BOD_U loading was achieved during a period when total population served and influent loading of BOD both increased by 35 percent!

Conclusion of the first leg of the stool



There was a dramatic nationwide decrease in BOD effluent loading from POTWs after the 1972 CWA despite a significant increase in population served!



The Second Leg: An examination of "worst-case" DO in waterways below point sources before and after the CWA

The second leg follows up on the first leg with the question—*Has the CWA's push to reduce BOD loading resulted in improved water quality in the Nation's waterways? And, if so, to what extent?* The key phrase in the above question is "to what extent?" Earlier studies by Smith et al. (1987a, 1987b) and Knopman and Smith (1993) conclude that any improvements in DO conditions in the Nation's waterways are detectable only within relatively local spatial scales downstream of wastewater discharges.

Because of the ecological significance of DO and its well-known causal relationship with the decomposition of organic carbon (carbonaceous BOD) and the decomposition of organic nitrogen and ammonia (nitrogenous BOD) from wastewater discharges, historical DO records provide an excellent environmental indicator for characterizing water quality responses to long-term changes in wastewater loading. A considerable amount of historical data is archived, and readily accessible, in STORET, USEPA's national water quality database.

A systematic, peer-reviewed approach was developed to identify water quality station records that encode the "signal" related to the water quality impact of point source discharges from the "noise" of millions of historical records archived in STORET.

The inherent difficulty in evaluating the effectiveness of reductions in point source loading is the need to isolate the water quality impact of discharges from the impacts caused by other confounding factors such as nonpoint sources, as well as the natural influence of streamflow and water temperature. In this assessment, a systematic, peer-reviewed approach has been designed to identify water quality station records that encode the "signal" related to the water quality impact of point source discharges from the overwhelming "noise" of millions of historical records archived in STORET.

With DO as the key water quality indicator, and keeping in mind the need to evaluate the change in the DO "signal" over time (before and after CWA) as well as over different spatial scales [i.e., river reaches (which average 10 miles in length), catalog units, and major river basins], the following "rules" for data analysis were used in a six-step data mining process to create before- and after-CWA data sets of "worst case" DO to be used in an unbiased, comparison analysis of downstream water quality conditions. The screening rules associated with each phase are listed below:

Step 1—Data Selection Rules

- DO data were extracted only for summer (July-September).
- Only surface DO data (within 2 meters of the surface) were used.

Step 2—Data Aggregation Rules From a Temporal Perspective

- 1961-1965 served as the "time-block" to represent persistent dry weather before the CWA and 1986-1990 served as the time-block to represent persistent dry weather after the CWA. These time-blocks were selected based on an analysis of long-term mean summer streamflow.
- DO data must come from a station in a catalog unit that had at least 1 dry year out of the 5 years in each before- and after-CWA time-block.

Worst case historical DO data were aggregated by three scales of spatial hydrologic units: reach, catalog unit, and major river basin.

Step 3—Calculation of the Worst-case DO Summary Statistic Rules

- For each water quality station, the 10th percentile of the DO data distribution from the before-CWA time period (July through September, 1961-1965) and the 10th percentile of the DO data distribution from the after-CWA time period (July through September, 1986-1990) were used as the DO "worst-case" statistic for the comparison analysis.
- A station must have a minimum of eight DO measurements within each of the 5-year time-blocks.

Step 4—Spatial Assessment Rules

- Only water quality stations on streams and rivers affected by point sources were included in the before- and after-CWA comparison analysis. Stations affected only by nonpoint sources were excluded. Out of 64,902 river reaches in the contiguous United States, 12,476 are downstream of a point source. Also, out of 2,111 catalog units, 1,666 have river reaches that are downstream of a point source.

Step 5—Data Aggregation Rules From a Spatial Perspective

- For each data set and time-block, the 10th percentile value from each eligible station was aggregated within the spatial hydrologic unit. (Since the scales are hierarchical, a station's summary statistic was effectively assigned to a reach *and* a catalog unit.) A summary statistic was then calculated and assigned to the spatial unit for the purpose of characterizing its worst-case DO. If a spatial unit had only one monitoring station within its borders meeting the screening criteria, the 10th percentile DO value from that station simply served as the unit's worst-case summary statistic. If, however, there were two or more stations within a spatial unit's borders, the 10th percentile values for all the eligible stations were averaged, and this value used to characterize worst-case DO for the unit.

Step 6—Development of the Paired Data Sets (at each spatial scale)

- To be eligible for the paired (i.e., before vs. after) comparison analysis, a hydrologic unit must have both a before-CWA and an after-CWA summary statistic assigned to it.

The comparative before- and after-CWA analysis of worst-case DO data derived using the screening criteria described above and aggregated by three scales of spatial hydrologic units (reach, catalog unit, and major river basin) yielded the following results.

Only water quality stations on streams and rivers affected by point sources were included in the before- and after-CWA comparison analysis.

The 311 evaluated reaches represent a disproportionately high amount of urban/industrial population centers.

Reach Scale Analysis

- *69 percent of the reaches evaluated showed improvements in worst-case DO after the CWA* [311 reaches (out of a possible 12,476 downstream of point sources) survived the data screening process with comparable before- and after-CWA DO summary statistics. The number of reaches available for the paired analysis was limited by the historical data archived for the 1961-1965 period].
- These 311 evaluated reaches represent a disproportionately high amount of urban/industrial population centers, with approximately 13.7 million people represented (7.2 percent of the total population served by POTWs in 1996). *As shown in Figure 6, the top 25 improving reaches saw their worst-case DO concentrations increase anywhere by 4.1 to 7.2 mg/L!*
- The number of evaluated reaches characterized by worst-case DO below 5 mg/L was reduced from 167 to 97 (from 54 to 31 percent).
- The number of evaluated reaches characterized by worst-case DO above 5 mg/L increased from 144 to 214 (from 46 to 69 percent).

Key finding at the reach scale: 69 percent of the paired reaches showed worst-case DO improvements after the CWA!

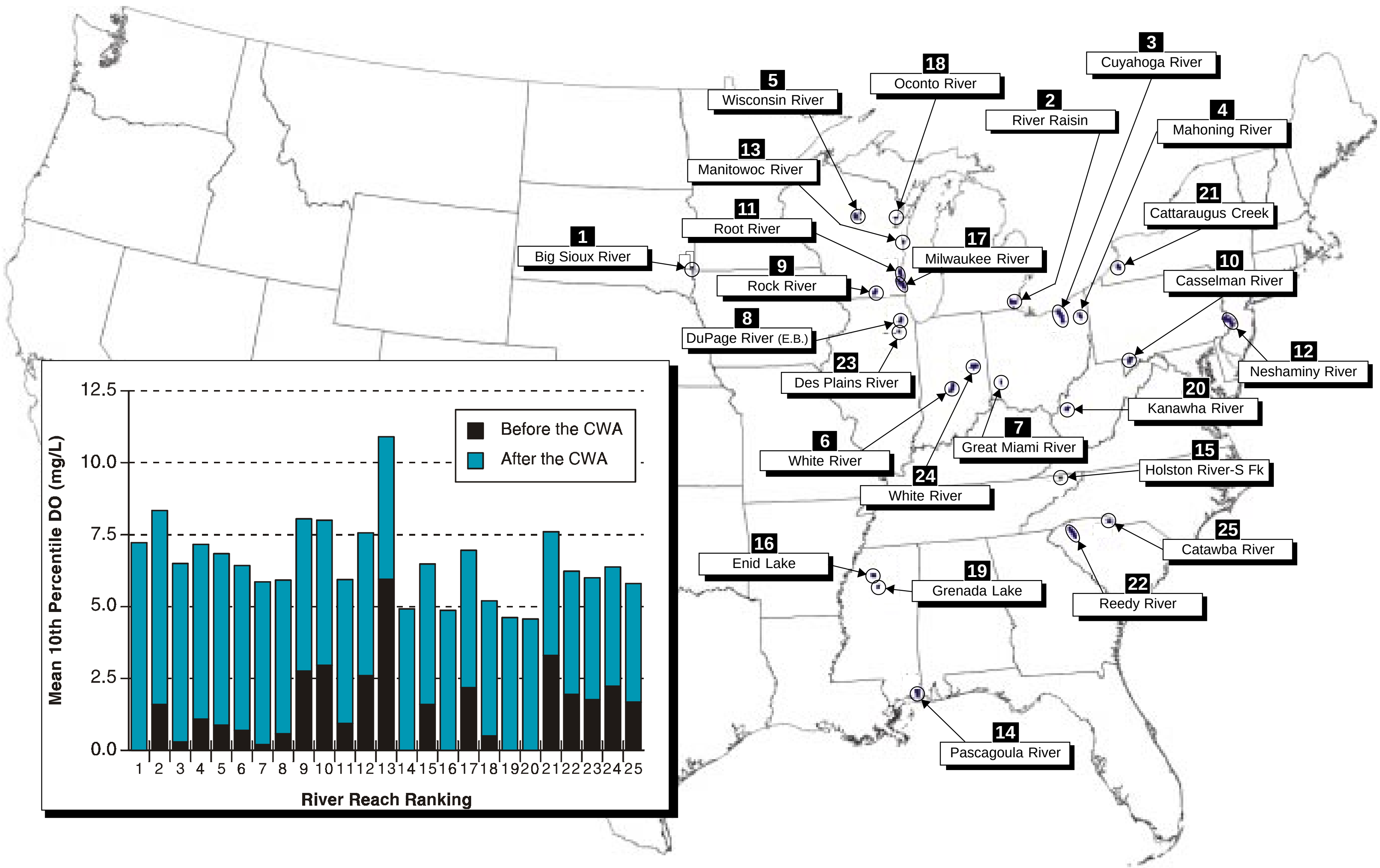


Figure 6

Location map and distribution chart of the twenty-five RF1 reaches identified with greatest after-CWA improvements in 10th percentile DO, 1961-1965 vs. 1986-1990. Reaches are ranked by greatest before- and after-CWA improvements.

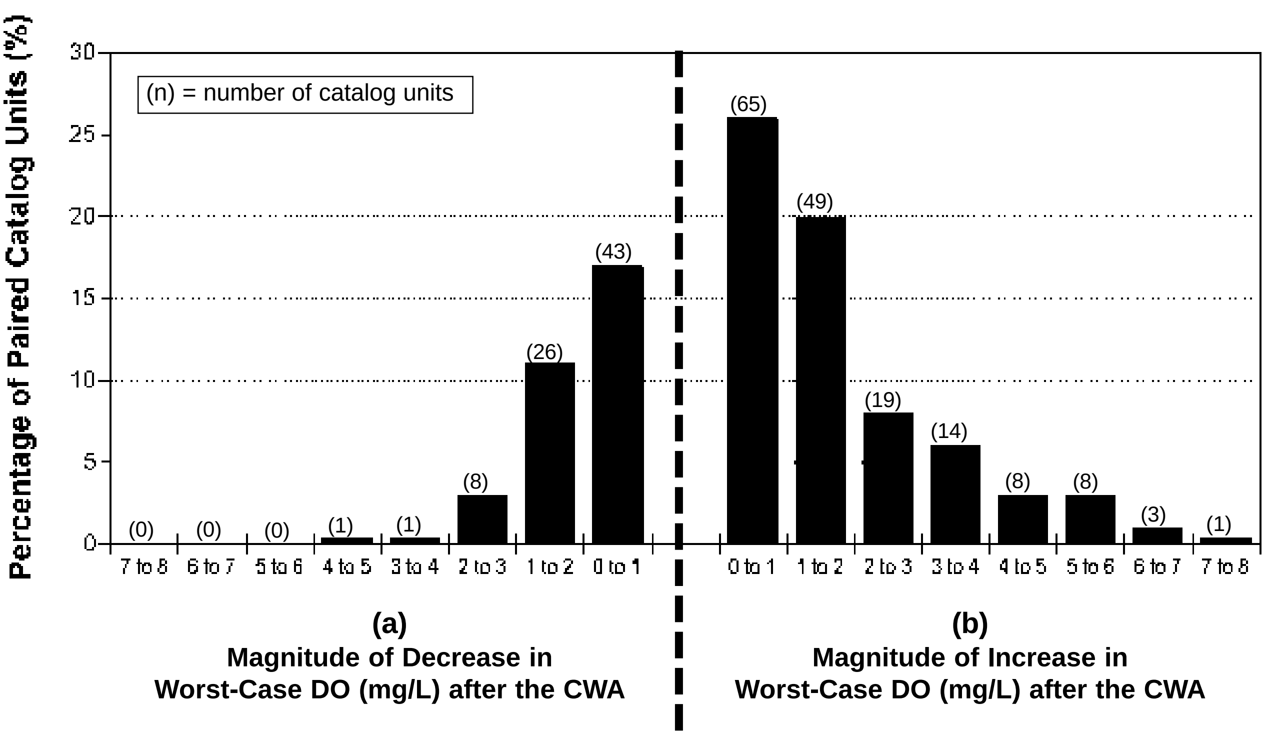
Key finding at the catalog unit scale: 68 percent of the paired catalog units showed worst-case DO improvements after the CWA!

Catalog Unit Scale Analysis

- *68 percent of the catalog units evaluated showed improvements in worst-case DO after the CWA* [246 catalog units (out of a possible 1,666 downstream of point sources) survived the data screening process with comparable before- and after-CWA DO summary statistics].
- The number of evaluated catalog units characterized by worst-case DO below 5 mg/L was reduced from 115 to 65 (from 47 to 26 percent). The number of evaluated catalog units characterized by worst-case DO above 5 mg/L increased from 131 to 181 (from 53 to 74 percent).
- As shown in Figure 7, 53 of the 167 improving catalog units (32 percent) improved by 2 mg/L or more while only 10 of 79 degrading catalog units (13 percent) degraded by 2 mg/L or more.
- These 246 evaluated catalog units represent a disproportionately high amount of urban/industrial population centers (see Figure 8), with approximately 61.6 million people represented (32.5 percent of the total population served by POTWs in 1996).

Figure 7

Frequency distribution of the mean 10th percentile DO for 246 catalog units that improved (n=167) and degraded (n=79) after the CWA. *(Source: USEPA STORET.)*



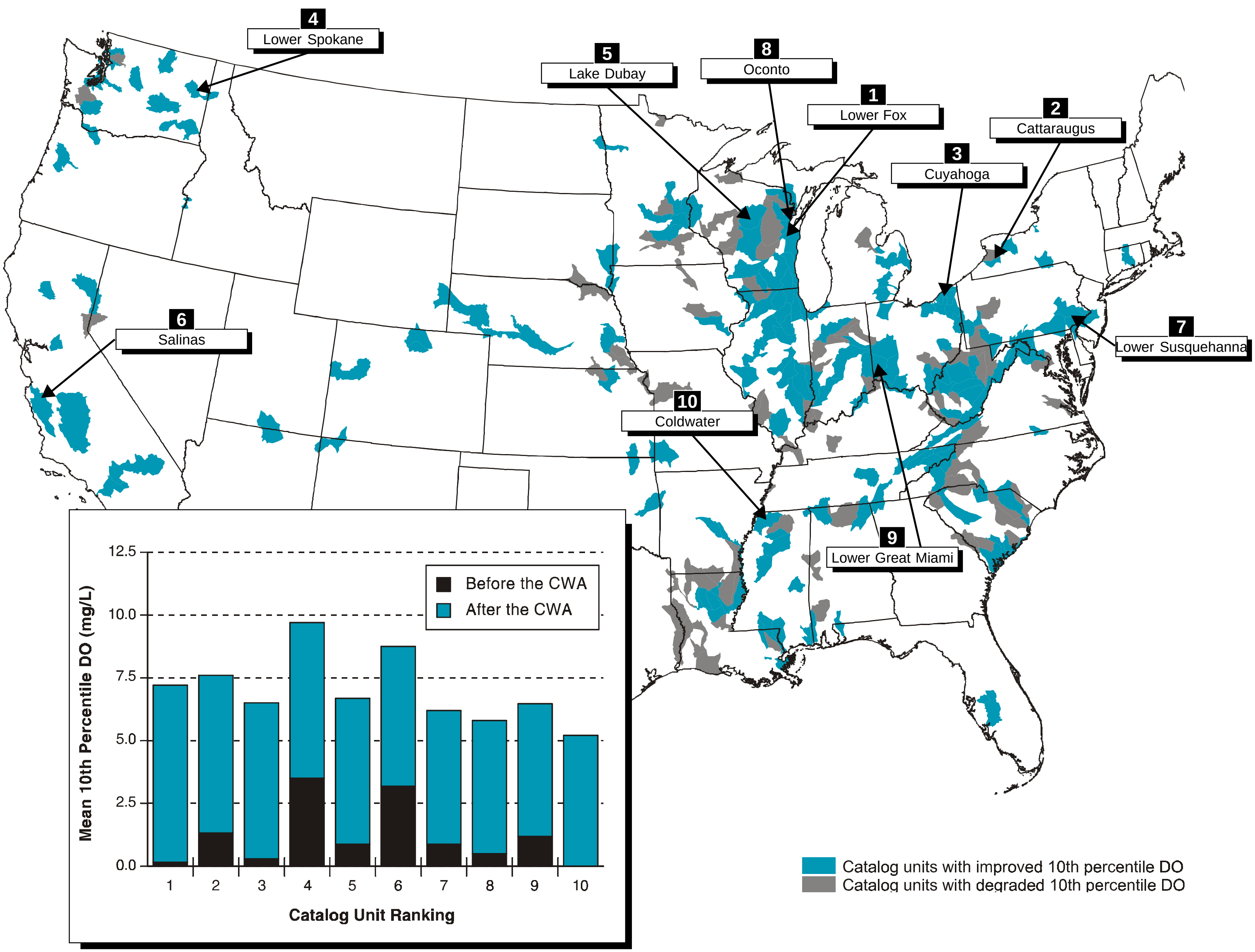


Figure 8

Location map of the 246 catalog units that improved or degraded in terms of 10th percentile DO after the CWA,1961-1965 vs. 1986-1990. The ten catalog units with the greatest after CWA improvements are highlighted and presented in a distribution chart.

(Source: USEPA STORET.)

Statistical tests run on the 311 paired reaches aggregated as a national whole revealed significant improvement in DO.

Major River Basin Scale Analysis

- A total of 11 out of 18 major river basins had sufficient reach-aggregated worst-case DO data for a before- and after-CWA comparison.
- *Based on two statistical tests, 8 of these 11 major river basins can be characterized as having statistically significant improvement in worst-case DO levels after the CWA!* The three basins that did not statistically improve under either test also did not have statistically significant degradation (Table 1).
- When all the 311 paired (i.e., before vs. after) reaches were aggregated and the statistical tests run on the contiguous states as a national whole, worst-case DO also showed significant improvement.

Key finding at the hydrologic region scale: 8 of the 11 major river basins with sufficient data had statistically significant improvement in worst-case DO levels after the CWA!

Table 1: Statistical Significance of Trends in Mean 10th Percentile (Worst-Case) DO by Major River Basin Before vs. After the CWA (1961-1965 vs. 1986-1990). *(Source: USEPA STORET.)*

River Basin	No. of Paired (before vs. after) Reaches	Paired t-test	Kolmogorov Smirnov test	Worst-Case DO (mg/L) 1961-65	Worst-Case DO (mg/L) 1986-90
All USA (01-18)	311	Yes	Yes	4.56	5.53
01 - New England Basin	1	*	*	4.30	6.90
02 - Middle Atlantic Basin	17	Yes	Yes	2.80	4.94
03 - South Atlantic-Gulf	61	Yes	Yes	4.10	4.73
04 - Great Lakes Basin	26	Yes	Yes	3.85	6.06
05 - Ohio River Basin	66	Yes	Yes	5.40	6.04
06 - Tennessee River Basin	19	Yes	No	4.08	5.23
07 - Upper Mississippi Basin	48	Yes	Yes	3.80	5.31
08 - Lower Mississippi Basin	25	No	No	3.79	3.94
09 - Souris-Red Rainy Basin	2	*	*	5.65	6.75
10 - Missouri River Basin	10	No	No	5.76	6.53
11 - Arkansas-Red—White Basin	7	No	No	5.36	4.60
12 - Texas-Gulf Basin	2	*	*	5.77	4.37
13 - Rio Grande Basin	0	*	*	--	--
14 - Upper Colorado River Basin	1	*	*	4.88	7.22
15 - Lower Colorado River Basin	0	*	*	--	--
16 - Great Basin	2	*	*	7.45	6.10
17 - Pacific Northwest Basin	17	Yes	No	7.61	8.21
18 - California Basin	7	Yes	Yes	5.61	7.58

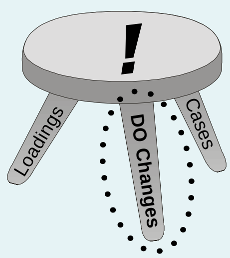
Paired t-test: 95% confidence - 2-sided test. Kolmogorov Smirnov test: 90% confidence, 2-sided test
*insufficient data for analysis

Closer examination of urban waterways helps identify, quantify, and document specific causes of water quality improvements.

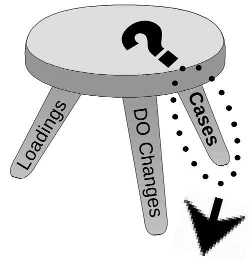
The second leg of the three-legged stool approach focused on assessing the change in the point source discharge/downstream worst-case DO signal over progressively larger spatial scales. The results of this analysis show that there were significant after-CWA improvements in worst-case summer DO conditions in two-thirds of the three hydrologic units at all three spatial data aggregation scales, from small subwatersheds of Reach File Version 1 river reaches (mean drainage area of 115 mi^2) to the very large watersheds of major river basins (mean area of 434,759 mi^2).

These results provide strong evidence that the CWA's requirements for municipal wastewater treatment using secondary treatment as the minimum acceptable technology supplemented by more stringent water quality-based effluent controls on a site-specific basis, yielded broad as well as localized benefits!

Conclusion of the second leg of the stool



There were significant after-CWA improvements in worst-case summer DO conditions in two-thirds of the hydrologic units at all three spatial scales!



The Third Leg: Case Study Assessments of Water Quality

The national-scale evaluation of long-term trends in water quality conditions associated with the second leg of the three-legged stool identified numerous waterways characterized by substantial improvements in DO after the CWA. The uniqueness of each waterway and the activities surrounding it requires an investigation to go beyond STORET to identify, quantify, and document in detail, the specific actions that have resulted in water quality improvements and associated benefits to water resource users.

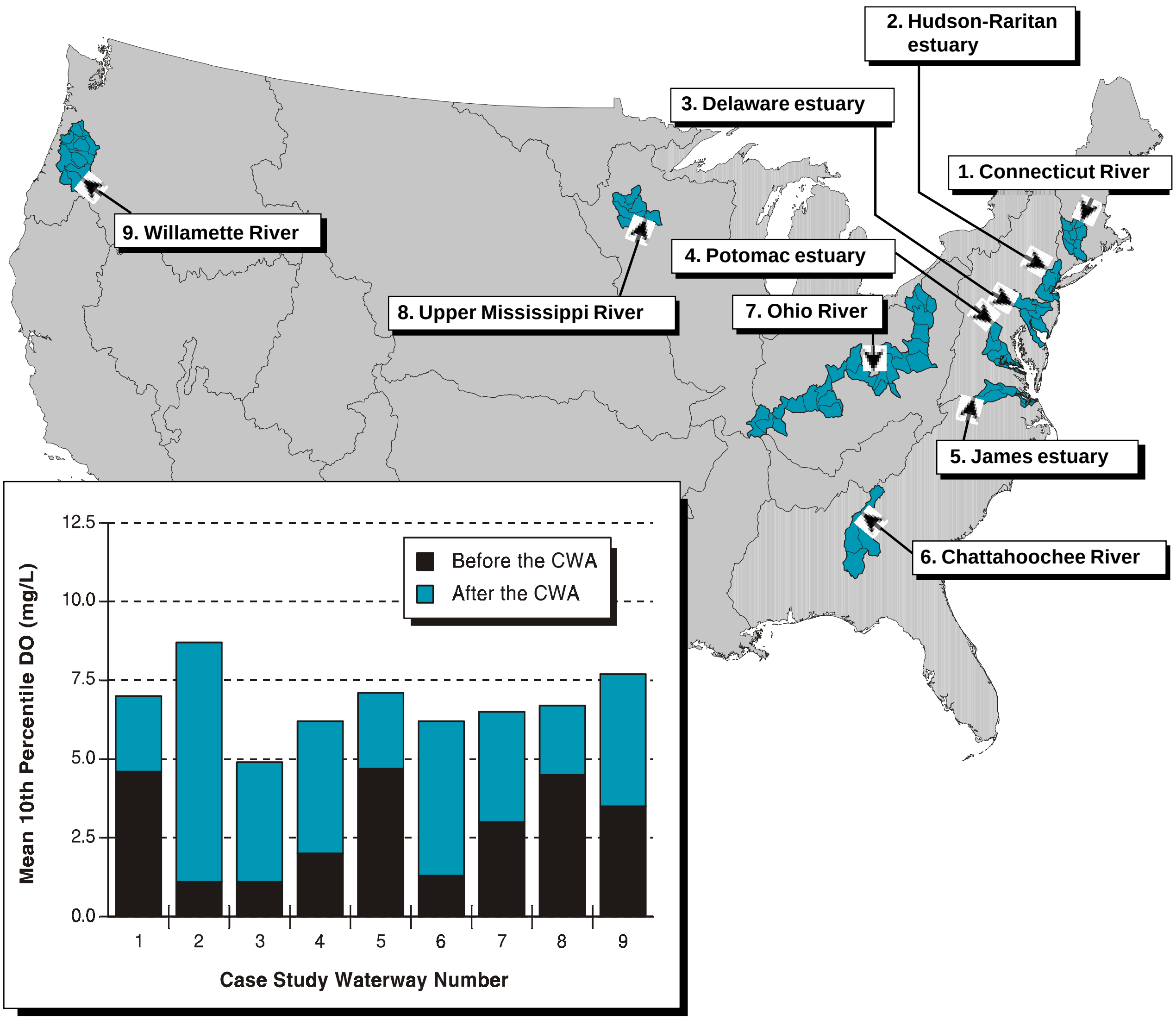
Nine urban waterways were selected for closer examination of the factors that caused improvement in local water quality and environmental resources (Figure 9). Note that the case study site selection was made prior to completion of the DO trend analysis described in the second study leg.

Most of the case study waterways were sites of interstate enforcement cases from 1957 to 1972, listed as potential waterways to convene state-federal enforcement conferences in 1963, or subjects of water quality evaluation reports prepared for the National Commission on Water Quality. Two sites (Ohio River and tributaries to the Hudson-Raritan estuary) were on a 1970 list of the top 10 most polluted rivers. Yet, interestingly, these case study waterways included none of the 25 river reaches with the greatest before- versus after-CWA improvements in DO found in the second leg of this study (see Figure 6).

These case study waterways represent heavily urbanized areas with historically documented water pollution problems. A variety of data sources, including the scientific literature, USEPA's na-

Figure 9

Location map of case study waterways and distribution chart of their before- and after-CWA mean 10th percentile DO for case study RF1 reaches: 1961-1970 vs. 1986-1995. *(Source: USEPA STORET.)*



tional water quality database, and federal, state, and local agency reports, were used to characterize long-term trends in population, point source effluent loading rates, ambient water quality, environmental resources, and recreational uses. Additional information was obtained from validated water quality models for the Delaware, Potomac, and James estuaries and Upper Mississippi River case studies to quantify the water quality improvements achieved by upgrading municipal facilities to secondary and greater levels of treatment as mandated by the 1972 CWA.

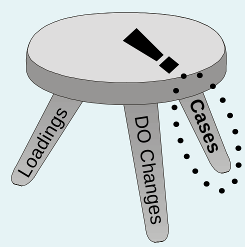
Key findings from the 9 case studies are highlighted below.

- In each of the case study urban areas, significant investments were made in expansions and upgrades to POTWs with commensurate increases in population served.
- Before the CWA, during the 10-year period from 1961-70, "worst-case" DO levels fell in the range of 1 to 4 mg/L for most of the case study sites; after the CWA worst case DO levels had improved to levels of almost 5 to 8 mg/L, during the 10-year period from 1986-1995.
- Water quality improvements associated with BOD_5, suspended solids, coliform bacteria, heavy metals, nutrients, and algal biomass have been linked to reductions in municipal and industrial point source loads for many of the case study waterways.
- Tremendous progress has been made in improving water quality, restoring valuable fisheries and other biological resources, and creating extensive water-based recreational opportunities (angling, hunting, boating, bird-watching, etc.) in all case study waterways.

The results of the third leg of the three-legged stool approach revealed that the significant investments made in municipal wastewater treatment resulted in dramatic improvements in restoring water quality and biological resources, and creating thriving water-based recreational uses in all the case study areas.

Although significant progress has been achieved in eliminating noxious water pollution conditions, remaining problems with nutrient enrichment, sediment contamination, heavy metals, and toxic organic chemicals continue to pose threats to human health and aquatic organisms for these case study waterways. Serious ecological problems remain to be solved for many of the Nation's waterways, including these case studies.

Conclusion of the third leg of the stool



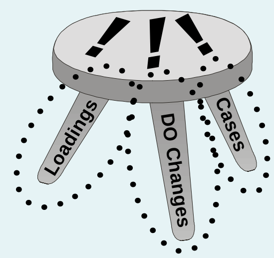
Tremendous progress has been achieved in improving water quality, restoring valuable biological resources, and creating recreational opportunities in all the case study areas!

Conclusion

The three-legged stool approach to answering the question —*Has the Clean Water Act's regulation of wastewater treatment processes at POTWs been a success?* was developed so that each of the legs could provide cumulative support regarding the success or failure of the CWA-mandated POTW upgrades to at least secondary treatment. Examining the results of each of the study legs, the conclusion is overwhelming that the stool does indeed "stand up!"

At both broad *and* local scales, the water pollution control policy decisions of the 1972 CWA have achieved significant successes nationwide in terms of reduction of effluent BOD from POTWs, worst-case (summertime, low-flow) DO improvement in waterways, and overall water quality improvements in urban case study areas.

Conclusion of the three-legged stool approach



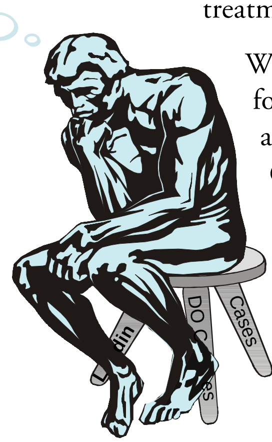
Each leg of the stool cumulatively and quantitatively supports the theory that the 1972 CWA's regulation of wastewater treatment processes at POTWs has been a significant success!

The data mining and statistical methodologies designed for this study can potentially be used to detect long-term trends in signals for water quality parameters other than DO (e.g., suspended solids, nutrients, toxic chemicals, pathogens) to develop new performance measures to track the effectiveness of watershed-based point source and nonpoint source controls.

As new monitoring data are collected, it is crucial for the success of future performance measure evaluations of pollution control policies that the data be submitted, with appropriate QA/QC safeguards, to accessible databases. If the millions of records archived in STORET had not been readily accessible it would have been impossible to conduct this national analysis of DO changes over the last quarter century.

Importantly, this study provides the first national-scale comprehensive evaluation of the effectiveness of the CWA's technology- and water quality-based effluent control policies in achieving the "fishable and swimmable" goals of the act. Population growth and expansion of urban development, however, threaten to erase these achievements unless continued improvement in wastewater treatment and pollution control occurs.

Many challenges remain. We must both maintain and enhance the progress already achieved in municipal wastewater pollution control as well as address other pollution sources and problems in the Nation's waterways.



With the newer watershed-based strategies for managing pollutant loading from point and nonpoint sources detailed in USEPA's *Clean Water Action Plan* (USEPA, 1998), the Nation's state-local-private partnerships will continue to work to attain the original "fishable and swimmable" goals of the 1972 CWA for all surface waters of the United States.

REFERENCES

Adler, R.W., J.C. Landman, and D.M. Cameron. 1993. *The Clean Water Act: 20 Years Later.* Island Press, Washington, DC.

Bondelid, T., C. Griffiths, and G. van Houten. 1999. *A national water pollution control assessment model.* Draft tech. report prepared by RTI, Research Triangle Park, NC for U.S. Environmental Protection Agency, Office of Science & Technology, Washington, DC.

Chase, N. 1995. A river reborn. Letter to the Editor, *Washington Post*, Washington, DC. January, 15.

GAO. 1986. *Water Quality: An Evaluation Method for the Construction Grants Program-Case Studies*. Report to the Administrator, U.S. General Accounting Office, Program, Evaluation and Methodology Division, U.S. Environmental Protection Agency, Washington, DC. Vol. 1, GAO/PMED-87-4B, December 1986.

Isaac, R.A. 1991. POTW improvements raise water quality. *Water Env. & Tech.* June, pp. 69-72.

Knopman, D.S. and R.A. Smith. 1993. Twenty Years of the Clean Water Act: Has U.S. Water Quality Improved? *Environment* 35(1):17-41.

Mearns, A. 1995. "Ready...Shoot...Aim! The Future of Water." Editorial. WEF *Water Env. Res.* 67(7):1019.

Patrick, R., F. Douglass, D.M. Palavage, and P.M. Stewart. 1992. *Surface Water Quality: Have the Laws Been Successful?* Princeton University Press, July 1992, Princeton, NJ.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987a. *Analysis and Interpretation of Water Quality Trends in Major U.S. Rivers, 1974-81.* Water-Supply Paper 2307. U.S. Geological Survey, Reston, VA.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987b. Water quality trends in the Nation's rivers. *Science* 235 (27 March 1987):1607-1615.

Smith, R.A., R.B. Alexander, and K.J. Lanfear. 1992. *National Water Summary 1990-91. Stream Water Quality: Stream Water Quality in the Conterminous United States-Status and Trends of Selected Indicators During the 1980's.* USGS Water Supply Paper 2400, U.S. Geological Survey, Reston, VA.

U.S. Census. 1996. *Population projections of the United States by age, sex, race, and Hispanic origin: 1995-2050.* Current Population Reports, Series p. 25-1130. Population Division, U.S. Bureau of Census, Washington, DC.

USDOI. 1970. *Municipal Waste Facilities in the U.S. Statistical Summary: 1968 Inventory.* Federal Water Quality Administration, U.S. Department of the Interior, Washington, DC.

USEPA (STORET). STOrage and RETrieval Water Quality Information System. Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1974. *National Water Quality Inventory, 1974 305(b) Report to Congress. Volume 1.* EPA 440/9-74-001. Office of Water Planning and Standards, U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1997. 1996. *Clean Water Needs Survey, Conveyance, Treatment, and Control of Municipal Wastewater, Combined Sewer Overflows and Stormwater Runoff. Summaries of Technical Data.* Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1998. *Clean Water Action Plan: Restoring and Protecting America's Waters.* U.S. Environmental Protection Agency, Washington, DC.

USEPA. 2000. *Progress in Water Quality: An Evaluation of the National Investment in Municipal Wastewater Treatment.* U.S. Environmental Protection Agency, Washington, DC.

WIN. 2000. Clean and Safe Water for the 21st Century: A Renewed National Commitment to Water and Wastewater Infrastructure. Water Infrastructure Network (WIN), Washington, DC, April.

Wolman, A. 1971. The Nation's Rivers. *Science* 174:905-917.